

Microstructure and Properties of the Ferromagnetic Shape Memory Alloy Ni_2MnGa

Marc De Graef, Carnegie Mellon University, DMR Award #0095586

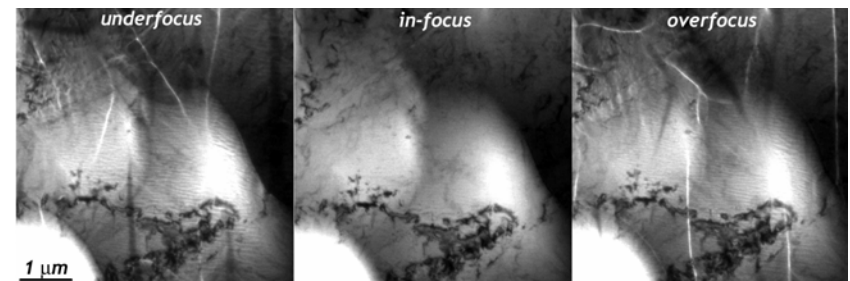
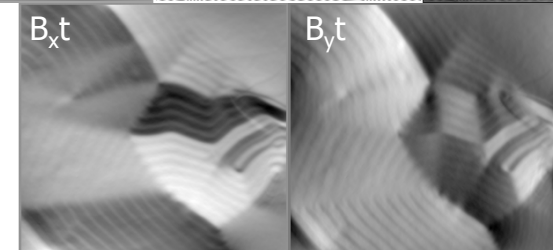
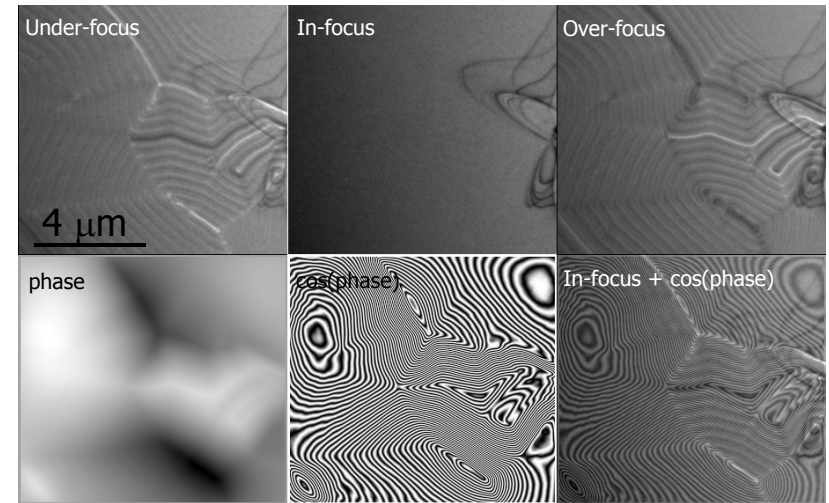
Complex Magnetic Domain Configurations

- First quantitative Lorentz observations of Ni_2MnGa and Co_2NiGa reveal rich variety of domains
- Evidence for magnetic tweed structures, I.e. magneto-elastic coupling
- Strong correlations between martensite and magnetic substructure
- Important for applications in actuators and sensors.



M. De Graef, M. Willard, M.E. McHenry, and Y. Zhu, "In-situ Lorentz TEM cooling study of magnetic domain configurations in Ni_2MnGa ," IEEE Trans. Magn., vol. 37, pp. 2663-2665, 2001.

Y. Kishi, M. Wuttig, M. De Graef, and D. Viehland, "Lorentz microscopy investigation of $\text{Co}(\text{Ni}_{0.205}\text{Ga}_{0.295})$ magnetic shape memory alloys: Coexistence of magnetic and elastic tweed-like pre-martensitic structures," submitted to *Applied Physics Letters*, 2002.



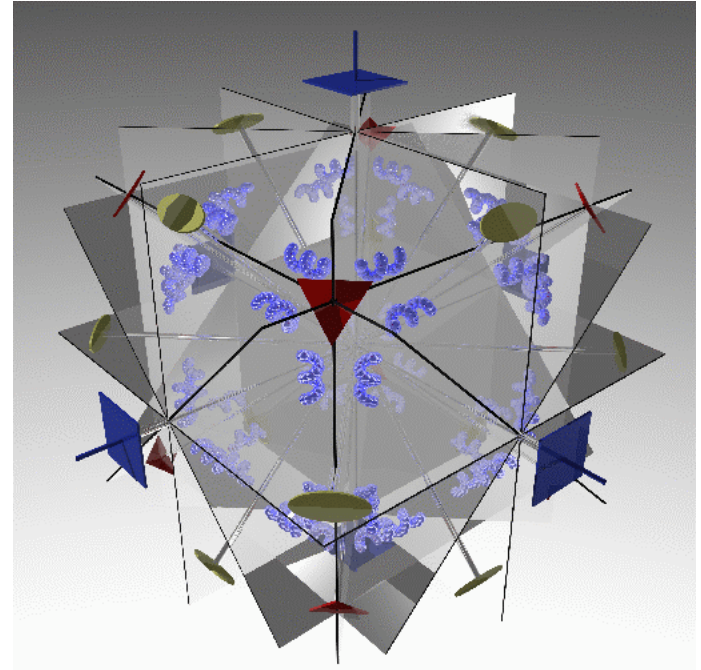
- We have carried out microstructural characterizations of Ni_2MnGa and Co_2NiGa materials. These materials are important because they can change shape under an applied magnetic field
- Two representative observations are shown in the figures:
- The three rows of images on the top show (first row) 3 experimental Lorentz images, taken with a 400 kV transmission electron microscope; from these images we can reconstruct the phase of the electron wave that traveled through the thin foil, using an algorithm that we are currently further developing. The resulting phase is shown in the first image of the second row. The cosine of the phase is shown in the middle, and combined with the in-focus image on the right. By taking the gradient of the phase, we can reconstruct the x and y components of the magnetization in the thin foil. The magnetization configuration shown here is the result of a minimization of the magnetostatic energy, which causes rapidly alternating magnetic domains.
- A similar behavior was observed in Co_2NiGa (images in bottom row), with the exception that the scale of the magnetization configurations is significantly finer than in Ni_2MnGa . We have obtained evidence for the existence of a “magnetic tweed structure” i.e., a finely modulated structure which may be a sign of a strong magneto-elastic coupling in these materials.
- This work is of importance to researchers who are studying the application of these materials in Micro-ElectroMechanical Systems (MEMS); in particular, a detailed study of the possible magnetization patterns is important for thin film single crystal applications. We have discovered that there is a film thickness below which the nature of the magnetic domains, and hence the magnetic properties of the film, changes.

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Training

- 2 graduate students (Shakul Tandon and SaiPrasanth Venkateswaran) have participated in research.
- Collaborations with Brookhaven National Laboratory and the University of Maryland were initiated.
- The PI was Chair of the 2nd Gordon Research Conference on Materials Education (sponsored by ISSI, TMS, and NSF).



Outreach

- Crystallographic teaching modules, started under NSF CAREER grant, were completed.
- Interactive web-based simulation modules for the teaching of transmission electron microscopy were created; the modules will accompany a graduate level textbook on the same subject, to appear in the Fall of 2002 (Cambridge University Press). The modules use the Interactive Data Language and are available at

<http://ctem.web.cmu.edu>

Two students have started on the program, each supported for 50%. They are currently working on the characterization of the microstructure of both Ni_2MnGa and Co_2NiGa materials. We have strong collaborations with Yimei Zhu, from BNL, and Manfred Wuttig, from UM. They provide us with materials and also with research time on their equipment.

In terms of outreach, we have completed a set of interactive crystallography modules which are now available through the PI's website. The routine cover 2D and 3D diffraction, and also the teaching of point group symmetries. The movie shows a 3D rendered representation of the highest symmetry cubic point group. There are 48 equivalent positions for the blue sphere.

Currently we are further developing a series of interactive modules for the teaching of transmission electron microscopy. Those modules cover about 20 different aspects of TEM, among others: defect contrast, convergent beam electron diffraction, short range order, phase contrast, Lorentz microscopy, and so on... Through these modules it is hoped that teachers worldwide will have novel tools to illustrate various image formation principles in electron microscopy. The underlying theory will be covered in the textbook, the manuscript of which is nearly complete.